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ABSTRACT

This paper discusses some means by which one might answer the question of "What makes problem solving hard?" In order to facilitate the investigations required to answer this question, a model of problem solving is needed. From some simulated solutions to a physics problem, several problem solving processes used by students are identified. A concise model of problem solving based on one of these solutions is then described. The model identifies steps that must logically be worked to complete the problem. These steps include: (1) reading; (2) sketching: translating words into symbols; (3) recognizing the law governing situations; (4) identifying definitions for quantities found in the law; (5) solving equations; and (6) making numerical substitutions (simplification skills). Limits to the validity of the model are discussed in light of the other solutions. Finally, an instrument that can be constructed by means of the model is described and its reliability tested. Subsequent papers will report on the results of applying the model to the learning of physics in a typical introductory course.
(Author/JN)

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A
CONCISE
MODEL
OF PROBLEM SOLVING:

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A REPORT
ON ITS RELIABILITY AND VALIDITY

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by

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This is the first in a series of papers analyzing what makes
the learning of problem solving hard.

*Work done while a graduate student at Kansas State University.

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Abstract

This paper discusses some means by which one might answer the question of "What makes problem solving hard?" In order to facilitate the investigations required to answer that question, a model of problem solving is needed. From some simulated solutions to a physics problem, several problem solving processes used by students are identified. A concise model of problem solving based on one of these solutions is described. The model identifies steps that must logically be worked to complete the problem. Limits to the validity of the model are discussed in the light of the other solutions. Finally, an instrument that can be constructed by means of the model is described and its reliability tested. Subsequent papers will report on the results of applying the model to the learning of physics in a typical introductory course.

INTRODUCTION

Physics has long been considered a difficult subject. Not only do students complain that it is difficult, but they sometimes complain that it is unreasonably difficult. At times they are taken seriously enough that a few engineering departments no longer require their students to take as many semesters of introductory physics. At other times, students are merely required to take physics and retake it if necessary until they fulfill their requirements. Working hard and doing poorly on tests is so typical of so many students taking the calculus based physics course for students of science and engineering that one wonders if everything one expects from students is actually as reasonable as one would like to believe.

A teacher of physics tends to look at what he expects from students in terms that presuppose a very sophisticated learner. He wants the students to see that one has built into these courses an integrated whole from several sciences: dynamics, statics, thermodynamics, electricity, magnetism, nuclear physics, and sometimes relativity and quantum mechanics. These various sciences interconnect to show a unity to science and to communicate some of the excitement of doing science. Moreover, each of these sciences can be applied to concrete situations and problems can be worked by combining the laws of these sciences with the conditions of the situation. This

latter activity takes up most of the learner's time in the introductory courses. It is presumably important to expose the students to this experience because they will need it later on in their engineering work and will probably never see so many simple and beautiful laws integrated together in any of their specialized work. Thus, this encounter with physics exposes them to an ideal situation that the students should aspire to strive for in their future work. A physics course would probably not be serving the students well, if it failed to make clear the power of science to interrelate principles and describe nature and made sure that the students see this for themselves in the work that is expected of them.

When one examines textbooks^{1,2} in physics from one hundred or so years ago, one can see that this intention has been part of physics teaching for some time. One can also see, however, that problem solving as we now know it is something relatively new. Old textbooks showed explicitly how the laws of science could be applied to explain various devices and demonstrations by explaining one demonstration after another. They gave the students very few problems to practice their abilities to apply any principles; problems using Newton's 2nd law are virtually non-existent, for example. Learning by solving problems appears to have become widespread just before the twentieth century. Apparently, when students were asked to learn to apply the laws of physics to work problems they began to find physics a difficult subject.

Some teachers of physics regretted this change: Casewell³ in 1933 felt that problems no longer existed to illustrate principles, but had become an end in their right; he called this a curse on physics instruction which was responsible for the declining enrollments in physics courses.

Casewell's analysis of student's dissatisfaction with physics appeared a half century ago. No one today would simply condemn problem solving as a whole. Nevertheless, people looking into the question of what makes physics hard, do suggest that one needs to look into what we make students do on these problems that might be responsible for making physics so hard for them. Fowler⁴ in 1969 asked if perhaps any of the processes is especially hard which presumably then means problem solving processes, since we ask students virtually nothing apart from solving problems. Rowe and DeTure⁵ in 1975, suggested a "fine grain analysis of the hierarchial structure of physics", presumably as it applies to the working of problems. More recently, Gerhart⁶ in 1979, suggested one look at typical kinds of materials and what students do with them to see what is so discouraging to them. That means, how do they relate to students' problem solving processes?

If one looks at introductory physics courses other than the one for pre-professional engineering and science students, one is likely to find somewhat disconcerting reasons concerning what makes physics hard. Strassenburg⁷ reports poor study habits; Behl⁸ finds that physic's reputation is self-perpetuating; and Arons⁹ reports that students prefer to entertain hopes

that the physics course will change rather than work at learning what is necessary. Apparently, one can find many reasons among immature learners for what makes physics hard. But even here, one cannot be completely certain that their difficulties stems from immaturity rather than problem solving processes that create insurmountable obstacles. Before one can choose between these two explanations, one will need to be able to identify the problem solving processes and investigate which ones are especially hard.

PROBLEM SOLVING SKILLS

Problem solving in the introductory courses rarely requires the student to make use of a single formula which is given in the textbook except for a few introductory exercises. Before too many problems like that have been completed, the student is expected to synthesize formulas for himself from the laws of physics. It is the steps in this latter process that need to be identified in order to speak of difficult problem solving skills. A bit of arbitrariness enters into the selection of a single model to describe the synthesis process, as can be seen in Table I, which shows that the processes used in synthesis can differ from individual to individual. Whether or not a solution obtained is correct or not is not the issue here, nor is the particular content used. What can be seen in these three attempted solutions is three different synthesis processes not found in the other two.

Insert Table 1 about here

The first solution explores what can be done with familiar results from statics: namely that the vertical forces must be in equilibrium. This solution begins with a wrong formula and operates on it with the intention of arriving at a usable result. Had the student begun with the correct expression for the dynamic case which includes the mass times the acceleration, this approach would have led to valid results. What would then be different about this solution from the other two is the need to complete the integrations which are extra operations not expected to be found in other solutions necessarily.

The second solution in Table I begins at first with an inappropriate formula describing the conservation of energy. The student recognizes its inappropriateness and attempts to generalize it by adding in suitable terms as common sense dictates. With the help of common sense and reasoning, this method can be made to work, despite errors in sign along the way. Such common sense reasoning is not uncommon and is found not only in the solutions of students, but also of instructors, and probably in more sophisticated forms in a number of physics textbooks. Such a method differs from the other two in that there is no systematic method for obtaining a correctly synthesized equation suitable for the problem. A solution is invented using reasoning and common sense processes which are not a necessary part of other solutions to this problem.

The third solution is based on a premise that is quite general: namely that the energy at one time in the motion is

equal to the energy at a later time, as long as no dissipative forces are acting. There are other ways to express this general law and with very rudimentary observations arrive at a synthesized formula. What is uniquely different about this solution is that it begins with a simple statement of sufficient generality to set up the desired equation. By recalling only well known definitions implicitly indicated by the statement of this law, the student arrives at the necessary synthesis.

That this might be the universal method of solving problems eventually discovered by students is certainly not the case. How, then, can one particular solution lead to a sufficiently general model for all student solutions? In one sense, any correct solution could have served as a model, because all must accomplish certain steps. In whatever way the student proceeds (or the instructor, for that matter) a relationship must be applied having sufficient generality to incorporate all the conditions of the problem. Furthermore, all these conditions will ultimately have to be incorporated into an expression, by whatever means the student chooses. In the case of the third method, they would be incorporated via simple algebraic substitution; in the other methods their incorporation might be more cumbersome or harder to explicate. The advantage of a method that begins with a suitably general principle is that it specifies all the steps that are logically necessary, but does not involve additional steps that might be needed by specific learners.

Other methods would therefore introduce additional skills that are not common to them all, involving extra propositions or additional operations. The method based on general laws has the advantage of not specifying additional steps or skills. However, one limit to such a model is that the student might actually be using additional and possibly very cumbersome skills in his own problem solving. Therefore, using this model to describe his work has the drawback that it makes it appear that he is having difficulties with very simple things, when in fact, they are very complex in the way they are actually being used by him.

CONCISE MODEL OF PROBLEM SOLVING

The model which is introduced here might be called the logical-step-model of problem solving since only the logically necessary steps are incorporated into it. It might be better characterized by its use of a major premise that serves to simplify the reasoning and operational manipulations so drastically. In that case, one might want to call it the general-form-of-the-law-as-the-major-premise-in-reasoning-model of problem solving. Since that is a rather cumbersome description, one might just call it the concise model of problem solving. That name distinguishes it from other problem solving processes that requires the student to arrive at a generalization by steps that are roundabout or inexplicable. It does not mean that all the actual written solutions not fitting the model exactly, are necessarily less concise, since one

can make up in one apparent step semi-relevant expressions with just a bit of imagination. Actual details in arriving at such expressions can be quite complex and simply have been left out. Thus, their conciseness is due to unexplained processes, not to concise reasoning. In such cases, there is a great deal of hidden structure involved.

Insert Table 2 about here

The concise model comes close to the "expert's" method of solving problems described by Larkin and Reif.¹¹ In an early article on understanding the problem solving processes they noted that an expert began with a general principle and then successively refined that principle. Considerable refinements in the concise model appear at step three of the procedures shown in Table 2. Larkin and Reif are then pointing out that precisely because the form of the law chosen is general, it permits refinement into a suitable form by identifiable and teachable recall processes.

In subsequent work by Reif,^{12,13} an expert's model of the mental processes is considered in order to shed light on how students solve physics problems. In this model, three kinds of knowledge are distinguished. First, there is knowledge of hierarchial structure such as the laws, principles, definitions, and classifications of a subject. Second, there are chains of associations in the knowledge base which include the operations one can perform on equations; these are brought to

a high degree of utility when learned as part of a set of well chosen worked examples, combined with episodic knowledge, these serve as building blocks (schema) for more complex solutions. Finally, Reif identifies knowledge of strategies (complex schemata) for reducing a problem into subproblems which the learner knows how to solve.

In terms of Reif's model, each student's solution in Table I relied apparently on different kinds of complex schemata. Actually, much simpler knowledge gaps could be the basis for their differences. Student number one may also have too limited a knowledge of worked examples using energy as well as weaknesses in knowledge of classifications and definition. His strategy relied on operations with forces because he might have misclassified the problem. Student two had too limited a knowledge of hierarchial structure involving principle and generalized them using a heuristic strategy. On the otherhand, student three integrated well organized hierarchial knowledge with a knowledge of suitable worked examples so that his strategy apparently required only recall of a general form of the law and recall of standard definitions.

What should be clear from this discussion is that there are several strategies open to the student not discerned by the concise model. Consequently, in adopting this model, one is not replicating strategies of the problem solver. One is limited to describing a minimum number of

steps that can logically be inferred to have been completed from the equation the student synthesizes, not the processes used to complete those steps. Each step implies a skill that the student must master by whatever hidden processes he uses. The minimal skills required by the model are listed in Table 3. Obviously, if the student is not drawing on general forms of the laws, the strategies and underlying skills for each step will be more involved than the logical steps indicated in Table 3.

Insert Table 3 about here

PURPOSE OF THE STUDY

The purpose of the present paper is to identify the limits of the validity of this concise model of problem solving and to assess its reliability as an instrument in analyzing student difficulties in problem solving. Subsequent papers will take up the findings of a study applying the model to the learning of problem solving skills in a typical physics class and discuss the implications for the teaching of physics. Its use as an instrument in analyzing the student's answers to physics problems will be taken up next. The paper will conclude with a discussion of the reliability found in scoring instruments based on the model.

Insert Table 4 about here

INSTRUMENTS

To apply the model, one needs first of all to identify the steps in the solution of a given problem. In the case of the problem shown in Table 1, a template showing each step is given in Table 4. Such a template is used to identify which steps the student has been able to complete. The content from the best solution found on the student's paper is transcribed to the appropriate place on the template.

Table 5 shows the solution of student (2) transcribed to the template. Once it is transcribed, one scores which of the steps of the template have been successfully completed. One needs to know which steps lead to what particular results, since students often skip steps. If a step has been "skipped" it might be called a bypassed step (b) or a curtailed step, but it should be considered as having been completed correctly if subsequent work shows that this is the case. Steps completed explicitly are scored (e).

Insert Table 5 about here

Some judgement is required in scoring a particular step. Is every detail of the step really indicative of the skill in question? For example in step (3) recognition of the correct law can be indicated by any expression resembling the law. Errors in writing down signs, subscripts, or even terms do not necessarily rule out that the correct law has been recognized. At step (5) discrepancies might exist in certain terms as well. Such discrepancies are really indications of errors

in using definitions, not in synthesizing them. So again, minor errors can be tolerated.

If one scored the solution at each step as strictly right or wrong based on the smallest of details, then "right" final answers will have "wrong" intermediate steps. Different readers might nevertheless score such not quite right steps in different ways, and scores would then differ from reader to reader depending on how they interpret inconsistencies. For that reason, the reliability of the scoring depends mostly on the agreement between different graders. For example, step (5) has been graded "b" (bypassed) but it might have been graded "r" (remaining to be done) or "u" (unwarranted). How much this affects reliability is taken up next.

Reliability of Scoring the Templates

Reliability has been checked in two ways. First, the self-consistency of the author's grading was checked on eleven questions by regrading the answers of four students drawn at random. When these were hurriedly re-graded six months later, the apparent self-consistency was only 70%. A more careful third check on the scores which did not agree arrived at a self-consistency of 89%. The self-consistency was lowest where the students made the most errors and was highest (94%) where the students did the work correctly. Overall, self-consistency is about 90%. Table 6 shows that self-consistency is about the same on each skill. Self-consistency is also about the same on each question though the results are not tabulated here.

Insert Table 6 about here

A second estimate of the reliability of these instruments is obtained by comparing the scores of the author to those obtained by other graders. The first attempt to measure the reliability of untrained graders produced very low agreement, only 30 to 60%. Some practice and feedback was then given to graduate students willing to give of their time. These graders were then presented with five student solutions to a fairly difficult question, difficult enough so that some of the staff made errors in solving it, but not so difficult that students skipped the problem. It was a problem where a lot of unwarranted expressions were expected. On that kind of material, these graders who had received some practice, were in agreement with the author's scores 83% of the time while a somewhat less experienced grader agreed only 56% of the time. These results are shown in Table 7. The results indicate that with sufficient

Insert Table 7 about here

practice, a high degree of agreement can be reached in scoring the templates once the content is assigned to the templates. A check on the agreement in assigning the content to the template after receiving training was not attempted. It is estimated to be about the same since scoring the templates depends on understanding where to place the student's content on the template. In that case, the over-all reliability would be expected to be about $(.83)^2$ or about 70%. Greater reliability is to be expected from additional training of graders. Potentially, if each problem is graded with sufficient care,

reliabilities of 90% can be expected even on difficult materials.

Conclusion

The templates constructed using the concise model of problem solving are evidently fairly reliable. They are also valid to the extent already discussed: namely, that the model indicates essential points that must logically be reached by any solution, but does not attempt to prescribe the actual processes followed by the student in reaching these points. The model therefore gives a description of skills in ways that understate all that is required. The student might need to struggle with far more processes (complex strategies) than are described by the model. For example, the model would lead one to believe that all that is necessary for each student is the recognition of some well known rule. This is possibly the case for what Larkin¹⁴ has called the "expert's" solution. For beginners arriving at the general form required to solve the problem, considerable inventiveness and reasoning might be required. Despite this approximateness of the concise model, it is expected to serve some useful purposes in assessing which logical steps the students are able to reach and which they are unable to reach by whatever means they have chosen to reach them. Irrespective of this approximate nature of the concise model, one can measure student learning of expert problem solving skills in far more complete detail than would be permitted by scoring the final answer right or wrong. One is checking the answer at various intermediate stages that can be inferred to have been reached with high reliability.

In a subsequent article this model will be applied to the learning of introductory physics for students of science and engineering. The model can be used to indicate at what rates the students make progress in learning the problem solving skills of physics. From the results, one can see which skills appear to be learned easily and which are learned inadequately. In short, the model introduced here permits a breakdown of some of the skills in physics problem solving and help one to see what might be done to improve the learning of physics. In that sense, the model appears to be relatively useful in investigations of what processes are hard to learn and should provide the means to narrow down the question of what makes the learning of physics or problem solving so hard.

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TABLE I

STUDENT PROCESSES IN PROBLEM SOLVING

PROBLEM

A rectangular block of length L and Area A is raised to a height h and then dropped. In terms of Young's modulus M and the density D, find the compression x of the block on impact. (The spring constant $k = MA/L$.)

SOLUTION (1)

$$\begin{aligned} mg &= k \, dx \\ \text{DAL } g &= k \, dL \\ \int \frac{DAg}{k} &= \int \frac{dL}{L} \end{aligned}$$

SOLUTION (2)

$$\begin{aligned} \frac{1}{2}mv^2 &= mgh \\ \frac{1}{2}mv^2 &= mgh + \frac{1}{2}kx^2 \\ x^2 &= 2mgh/k \\ &= \frac{2DghL^2}{M} \end{aligned}$$

SOLUTION (3)

$$\begin{aligned} E_{\text{top}} &= E_{\text{bot}} \\ KE_{\text{bot}} + PE_{\text{top}} &= KE_{\text{bot}} + PE_{\text{bot}} \\ 0 + mg(h+x) &= 0 + \frac{1}{2}kx^2 \\ \text{DAL } gh &= \frac{1}{2} \frac{MA}{L} x^2 \\ x^2 &= \frac{2DghL^2}{M} \end{aligned}$$

Solution (1) This simulated solution relies on deductive reasoning and an incorrect premise. Had the student included the impulsive force, this approach would have led to a correct answer.

Solution (2) This solution recalls a very particular relationship from previous problem solving and generalizes the relationship to fit the present problem by inventing an almost appropriate expression. Common sense tells the student not to worry about the signs in the expression he has invented, and he arrives at the correct answer.

Solution (3) This solution shows the student recalling a general form of the Work-energy principle that applies when no outside forces are acting. He arrives at a correct solution mostly by substituting familiar definitions. He also uses some common sense in dropping the comparatively small mgx term to facilitate his arriving at a solution.

These three simulated solutions illustrate the different processes that students can bring to a problem. The deductive skills shown in solution (1) might lead to a correct answer after many trial solutions, all of which are part of this student's problem solving processes. Solution (2), on the other hand appears to be relatively concise, but this is because the student's reasoning is not apparent. This is in sharp contrast with solution (3) where all the steps are evident.

TABLE 2

STEPS IN THE CONCISE MODEL

Whenever the student is given a problem that cannot be solved by plugging into a given formula, the student is expected to synthesize his own formula. All the steps given here must then be completed. Since the student might use additional processes, these steps describe the minimal number of steps that must be completed.

STEP (1): READ the problem noting with care what is given and what is asked for. Not to do this risks solving a different problem.

STEP (2): TRANSLATE the given and unknown quantities into symbols; MAKE a sketch. Failure to do this risks working the wrong problem or a nonsensical problem.

STEP (3): RECOGNIZE which law applies to this situation.

STEP (4): IDENTIFY which definitions (such as those for kinetic energy, etc.) are required by analyzing the law and the given and unknown quantities.

STEP (5): SUBSTITUTE the definitions into the law.

STEP (5'): SOLVE the equation synthesized in step (5) for the unknown in terms of the known. This step is not necessarily trivial since this might require several cycles of the above steps to arrive at a suitable formula. Mathematical laws and principles are required here instead of physical ones as a rule.

STEP (6): EVALUATE the formula obtained numerically (or asymptotically, if that is desired). CHECK on the validity of the results.

All of the above steps correspond to the levels described in Bloom's Taxonomy^a. This is true in the sense that if the student carries out five of these steps, for example, then he will have completed a problem at level five in Bloom's taxonomy. To reach a given level the student must complete all the previous specified steps at the lower levels.

TABLE 3

SKILLS IN COMPLETING STEPS IN THE CONCISE MODEL OF PROBLEM SOLVING

- SKILL (1): Reading
- SKILL (2): Sketching; translating words into symbols
- SKILL (3): Recognizing the law governing situations.
- SKILL (4): Identifying definitions for quantities found in the law.
- SKILL (5): Substituting algebraic expressions.
- SKILL (5'): Solving equations.
- SKILL (6): Making numerical substitutions; simplification skills.
-

TABLE 4

SAMPLE TEMPLATE

Steps needing completion in the concise model of problem solving are indicated below for the problem found in Table 1.

STEP (1) STATE: "Obtain a relation for the compression."

STEP (2) STATE: $x=?$ SKETCH: Block at points of its motion.

STEP (3) STATE: $E_{top} = E_{bot}$ or an equivalent statement.

.....

STEP (4) STATE: $D=m/V$ $V=AL$ $KE_{top}=0$ $KE_{bot}=0$ $PE_{top}=mgh$ $PE_{bot}=\frac{1}{2}kx^2$

.....

STEP (5) STATE: $mgy + 0 = \frac{1}{2}kx^2 + 0$ $DAL gh = \frac{1}{2} Max^2/L$

.....

STEP (5') STATE: $x^2 = 2DL^2gh/M$

.....

TABLE 5
TEMPLATE WITH SOLUTION AND SCORES

Content from Solution (2) on Table 1 has been transcribed to the template

STEP (1) ^b STATE: "Obtain a relation for the compression."

STEP (2) ^b STATE: $x=?$ SKETCH: Block at points of its motion.

STEP (3) ^b STATE: $E_{top} = E_{bot}$ or an equivalent statement

$$\frac{1}{2}mv^2 = mgh + \frac{1}{2}kx^2$$

STEP (4) STATE: ^b $D=m/V$ ^b $V=AL$ ^b $KE_{top}=0$ ^b $KE_{bot}=0$ ^b $PE_{top}=mgh$ ^b $PE_{bot}=\frac{1}{2}kx^2$

STEP (5) STATE: ^b $mgy + 0 = \frac{1}{2}kx^2 + 0$ ^b $DAL gh = \frac{1}{2} MAX^2/L$

STEP (5') ^e STATE: $x^2 = 2DL^2gh/M$

$$x^2 = 2DghL^2/M$$

TABLE 6

SELF - CONSISTANCY IN SCORING EACH SKILL

SKILL (2)	SKILL (3)	SKILL (4)	SKILL (5)	SKILL (5')
90%	92%	91%	86%	89%

TABLE 7

AGREEMENT OF SCORES USING TRAINED AND UNTRAINED GRADERS

TRAINED GRADERS			LESS TRAINED GRADER
(1)	(2)	(3)	(4)
82%	86%	82%	56%

REFERENCES

1. Atkinson, E., Elementary Treatise on Physics, Experimental and Applied, Seventh Edition. William Woods and Co., New York. 1883.
2. Privat-Deschanel, A. Elementary Treatise on Natural Philosophy. D. Appleton, New York. 1878.
3. Casewell, A.E. "The Content of the First Year Course in College Physics." American Physics Teacher 1: 95-98; 1933.
4. Fowler, J.M. Content and Process in Physics Teaching." American Journal of Physics 37: 1194-1200; 1969.
5. Rowe, M.B., and DeTure, L. A Summary of Research in Science Education: 1973. Interscience Publication, New York. 1975 p. 58.
6. Gerhart, J., Editorial, The Physics Teacher, 17 no 2; 1979, p. 83.
7. Strassenburg, A.A. Letters to the Editor, American Association of Physics Teachers Announcer 9, No 1; 1979 p. 26.
8. Behl, Y.K., "What Makes Physics Hard?" Contributed paper, American Association of Physics Teachers Summer Meeting Las Cruces, NM. 1979 and private communication.
9. Arons, A. Letters to the Editor, American Association of Physics Teachers Announcer 9 No 3, 1979. p 15.
10. Larkin, J.H. and Reif, F. "Understanding and Teaching Problem Solving in Physics" European Journal of Education 1: 191-203; 1979.

11. Reif, F. Mimeographed Manuscript on Cognitive Mechanisms,
Berkeley, Oct. 1979.
 12. Reif, F. "Teaching Problem Solving--A Scientific Approach,"
The Physics Teacher 40: 310-316; May 1981.
 13. Larkin, J.H., McDermott, J., Simon, D.P., and Simon, H.A.
"Expert and Novice Performance on Solving Physics
Problems," ...Working Paper No. 410, Carnegie-Mellon
University, Dec. 1979.
- A. Bloom, B.S. Taxonomy of Educational Objectives: Cognitive
Domain. David McKay Publishing Co., New York. 1956.